Risk Management at JPL – Practices and Promises

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Abstract— Risk Management (RM) at JPL has developed in the past few years from a pioneering effort instituted and implemented by a few brave projects to a methodology required on all projects and supported by a well-defined process and training activity. This paper discusses the beginnings of Risk Management at JPL, the lessons learned form those experiences, and the evolution to the current process.

The JPL process is discussed in its salient features – planning, identification and assessment, decision-making, and risk tracking. For instance, the methods for assessing risk likelihood and impact that are provided to Project Risk Management teams are rich and varied, and have not been standardized to the degree expected in the beginning, and in some sense desired by the NASA and Institutional management. This has enabled projects to tailor the style of RM to the characteristics of the project and the management objectives of the Project Manager, and has avoided some frustration and reluctance to adopt a "new" required activity in the implementation of the project. Some of the risk analysis methods are described. Specifically, the distinction between qualitative and quantitative methods are delineated, with the advantages and disadvantages of each described from the viewpoint of the practitioners.

Risk Management strategies, and the measures developed to allow the desired decisions in pro-actively using resources reserves to mitigate risks are presented. Finally, some observations of the direction of future improvements are discussed.

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1. INTRODUCTION

Risk Management at JPL has developed over the past 6-7 years as a recognized, specific and necessary element of the management, control and oversight of a successful Space-Flight Project. This has occurred because a) the programmatic space exploration environment has changed and b) NASA, our customer, has identified the necessity for it. With some 20 or more projects at JPL currently in the NASA Provide Aerospace Products and Capabilities (PAPAC) process (as defined by NASA NPG 7120.5 [1]), the process has evolved from its initial applications in projects born in the mid-90's, and certain elements are emerging as effective and practical activities. All projects are practicing Risk Management. Other lessons have been learned, and the process has been adapted to those lessons. Still other lessons are yet to be learned. It is in this degree of maturity that this paper is set, and the methodology described.

2. THE PIONEERING PRACTICES

Three projects which began the practicing of Risk Management at JPL are the Mars Pathfinder (MPF) project, the Mariner Global Surveyor (MGS) project and the Space Infrared Telescope Facility (SIRTF) project. These projects' approaches define the major elements of the Risk Management practiced on the projects currently approved and being implemented today, and it is worth examining the elements of each approach.

Mars Pathfinder

Mars Pathfinder successfully landed on Mars, deployed the Sojourner Rover, and returned scientific data and experiential information on surface operations beyond all expectation. MPF developed risk lists and used their qualitative assessments to make pro-active mitigation decisions and guide testing and validations, working on a demanding schedule, and considering significant technology development. The process was not as formalized as current projects, but used some innovative analysis techniques such as Probabilistic Risk Analysis, and schedule uncertainty analysis to assist the assessment of the severity of key risk areas. The project pro-actively used the budgetary resources available to mitigate technical risk, and to trade for additional technical margins where possible. These lessons have been important inputs to the current Risk Management process.

Mars Global Surveyor

The MGS project, which is currently in an extended operational phase in orbit around Mars, was a re-fly of the ill-fated Mars Orbiter project (MO). It inherited the anxiety of correcting causes of the previous failures and avoiding similar new pitfalls, while at the same time inheriting major elements of hardware and software, and the good experience of having little in the way of new technology to develop. The project approach therefore emphasized thorough design and test verification and validation, with reasonable reserves in budget and schedule to mitigate risks in implementation. Risk Management involved the prioritized attention to not failing, and staying within the budget. Cost was selected as the risk metric, and all risks were quantitatively assessed relative to the cost impact should they occur. Risks were also assessed with respect to the potential impact on technical resources (e.g. mass and power) and mitigation decision were made taking the trade-off of usage of all of these resources into account. A major lesson learned in this approach was that appropriate reserves could be justified to the program and agency customers through these risk-related assessments.

Space Infrared Telescope Facility

SIRTF was the first project to be held up to the light of NASA independent assessment as defined by NPG 7120.5 [1]. JPL as well as the other NASA centers have embraced this set of requirements, which includes requiring a Risk Management plan, a life-cycle formal risk management activity, and the assessment of high risk areas by external management review panels. The project is currently in the implementation process, with launch expected in 2002.

SIRTF's approach to Risk Management closely adapts the practices outlined in reference [1]. The risks are qualitatively assessed, and ranked according to the severity of the risk, which is a combination of the likelihood of occurrence and the consequence of the event if it should occur. SIRTF also developed a risk documentation and tracking web-based tool which has been the model for the current tool maintained at JPL and used on many of the projects in development today.

3. Risk Assessment External to the Project

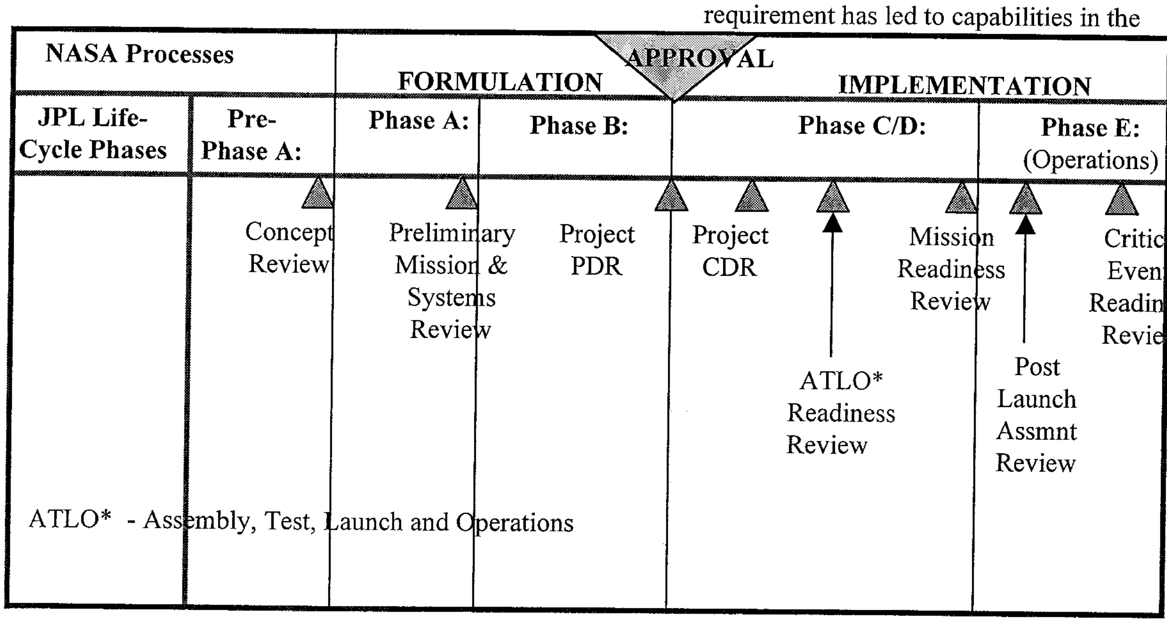
In addition to risk assessment within the project management activity, practices have been instituted for external review and assessment of NASA flight projects that bear on the direction in which project Risk Management is heading, and these are briefly discussed here.

Independent Review and Assessment

Through the NASA policy directives [2] and practices [1] for project management, external review processes have been instituted which specifically assess risk during the development process. The Governing Program Management Council (GPMC), which consists of the senior center management group, reviews the project status, problems and risks at major milestones in the life-cycle (Fig 1). The Systems Management Office at JPL provides the expert review teams that report their assessments to the GPMC along with the project's review. Risk is specifically assessed by an independent review team and presented at the GPMC deliberations for readiness to launch and conduct successful operations. The recent emphasis on assessing risk external to the project process has helped to focus the current project risk management practices.

Review and Concurrence on Primary Risks

NASA requires that the GPMC concur in the disposition of what that document calls "Primary" risks [1] – that is those risks assessed in the highest prioritized category. The concurrence requires the project to demonstrate that any accepted risks in this category have been adequately studied for mitigation or removal, and the approaches available to accomplish this are not practical or acceptable. This requirement has led to capabilities in the



JPL Risk Management process to accommodate them.

4. Process Overview

The JPL Risk Management (RM) process is composed of four major sub-processes: RM Planning, Risk Identification and Assessment, Decision-making, and Risk Tracking. The process is continuously iterated throughout the project life-cyle. Figure 2 illustrates the process flow.

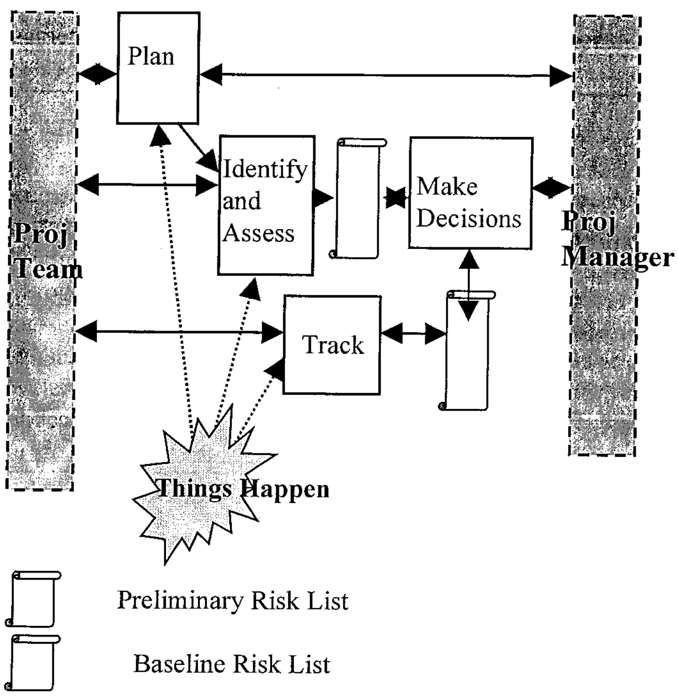


Fig 2 - RM Process Flow

As risks change throughout the project development, this process is repeated and re-iterated frequently and regularly. Also new risks emerge and are processed into the set of assessed risks. There are two essential features of the process. First, the Project team participates fully in the process. Each area of expertise contributes identification and assessment of risks, and indeed "owns" the identified risks until the risks are retired. Secondly, the project manager makes the decisions involving whether or not and how to expend resource reserves to mitigate risk, or redistribute the risk through changes to the project.

Planning

Each project is required to provide a plan describing how risk management will be implemented on the project. This is a metric tracked by the Risk Management process owner within the Safety and Mission Success office at JPL. The plan is developed in a preliminary version at the beginning of phase A (see fig. 1). This is sometimes required by the proposal process by which JPL "wins" some of the projects we implement. The final version is required for confirmation, which is a major approval point where the NASA Enterprise provides funds to implement the project. At this time the project demonstrates a good understanding of not only how they will manage risks, but what the major risk areas are that will predominate, and what specifically is planned for those areas.

This plan becomes not only an indication to the NASA customers and Laboratory management that the project has an adequate approach to dealing with risk, but also a reference for project personnel. It is especially valuable to the risk team, defining specifically how risk will be identified and assessed, how risk trades and analyses will be conducted, and how they will be tracked.

Identification

The major sources and methods of risk identification on a flight project are shown in fig 3. At the beginning of a project risk is assessed through analogy with like projects, experience gathered across as wide a spectrum of agencies and implementers as possible, and as accurate an assessment of the project concept as can be defined. The risks are very high-level, but it is critical to adequately scope the resources, both technical and programmatic, which will be required as reserve to deal with them. JPL has developed rules/ guidelines called "Design, Verification, Validation, and Operations Principles for Flight Projects" [3], in order to enable objective identification, and independent assessment, of potential risk areas at the early stages of a project. **Each project is required to provide a self-assessment of compliance to the principles**, and the principles are also used by the independent assessment teams. The principles include cost and schedule guidelines as well as those for system, hardware, and software technical implementation. Risk is identified and assessed against the criteria provided in the principles. An example below sets the guidelines for carrying mass uncertainties, and system margins, as a function of time in the life-cycle.

A **Mass uncertainties** (at start of phase B) shall be assigned to system elements as follows:

- New designs - 30%
- Inherited designs - 15% (or more depending on the outcome of inheritance reviews.)
- Inherited hardware - 10% (or more depending the degree of change required) or - 2% if hardware is totally known to be without change.

B Adequate margin shall be provided to accommodate growth. **Spacecraft system level mass margin** shall be at least 30% at the phase B start, 20% at Project PDR, 10% at CDR, 5% at ATLO Readiness and 2% at launch or as set by the project manager.

Table 1 – Mass Margin Design Principle (excerpt)

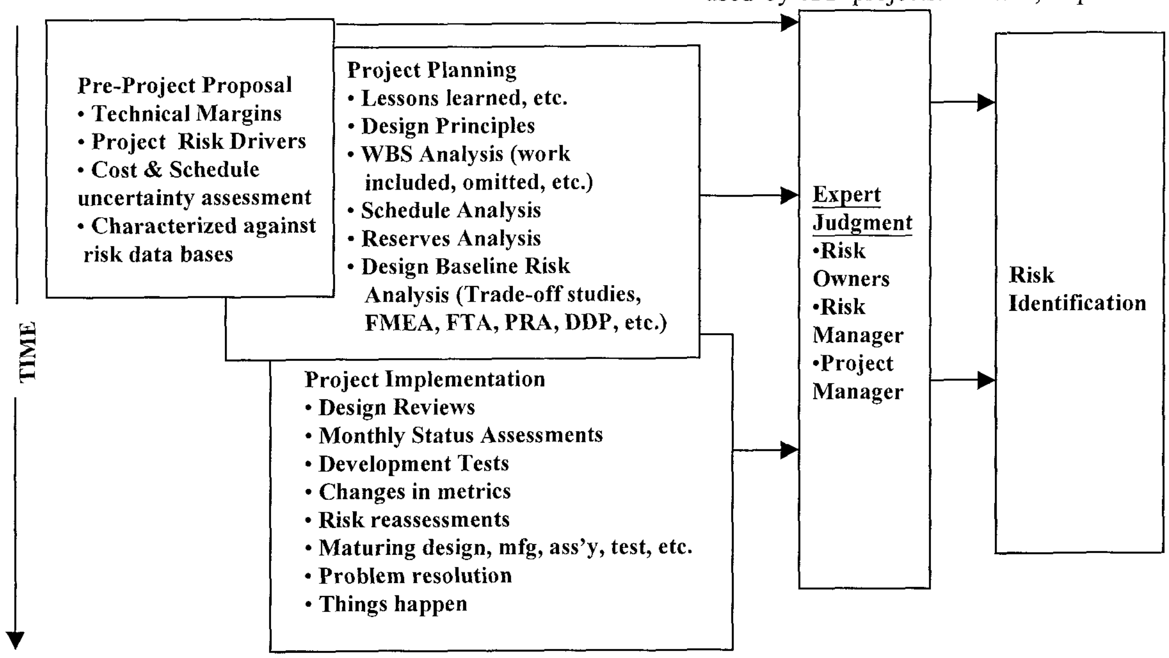


Fig 3 - Sources for Identifying Risk

Fig 3 indicates sources of inputs to identifying risks as the implementation matures. Specific analyses of project parameters will flush out more risks. Once the baseline program is planned, schedule and budget uncertainty analyses will not only identify new risks, but help in assessing the severity of the known risks, and in analyzing the aggregate project risks. At JPL, we have traditionally used such risk-identifying and assessing tools as Fault Tree Analyses (FTAs), and Failure Modes Effects Analyses (FMEAs). Probabilistic Risk Analyses (PRAs) have been done for numerous missions in the past, both to support required risk-averse designs as required to obtain launch approval for nuclear fueled power sources, and to support decision making for alternative implementations.

The essence of the JPL risk identification process is that risk areas can be identified in a number of ways, can arise from a variety of sources, and need then to be assessed by the project experts for consideration as project risks. Thus, expert judgment is the filter through which risks are added to the risk list.

Assessment

Risks are assessed using a consistent and uniformly applied set of criteria. These criteria are defined in the RM Plan. The risk is defined as a potential adverse event in the future. The criteria allow the assessor to measure (either qualitatively or quantitatively, or both) the likelihood of the event occurring and the consequence of its occurrence. There is not a standard required set of criteria that must be used by JPL projects. Rather, experience to date suggests that the most important aspect of defining the criteria is that the Project, and the Project manager, embrace them, and makes them central to their view of the project situation.

Some managers use qualitative criteria more effectively, and others believe that assessing risks quantitatively is the most important value of the activity. Thus the JPL RM process embraces both methods.

Qualitative Criteria– Such criteria are based on ordinal evaluation. Risks can be ranked but within a rank, their relative severity can't be assessed, and they can't be aggregated to assess a total. Examples of the criteria used by different projects to assess likelihood qualitatively are shown in table 2.

Some qualitative criteria use quantitative ranges to guide the assessors. In fact, the distinction becomes murky

Adjective	Example 1	Example 2
High	very likely	>90%
Significant	likely	Between 50 and 90%
Low	unlikely	Between 10 and 50%
Negligible	Very unlikely	<10%

Table 2 – Examples Of Qualitative Likelihood Assessment Criteria

Examples of qualitative criteria for assessing consequence are shown below in table 3 and 4. In the first example, the impact to the mission can be ranked high if the risk occurring would bankrupt the reserves or would threaten mission failure. This introduces the idea of measuring (qualitatively in this case) the risk against a pre-defined set of criteria against which the project measures itself, and which can be used by the independent assessors mentioned earlier. NASA has begun to require that these "Success" criteria be defined at the beginning of the projects, and documented in the Project definition documents (the Project Plan, for example.)

Adjective	Criteria
High	Not repairable within remaining resources allocated to the system provider OR Level 1 Requirements (Mission Success) are not achieved
Significant	Depletes remaining reserves and/or severely degrades mission success
Low	Severe impact to remaining resources and does not degrade mission success
Negligible	Measurable impact to resources or some impact to secondary mission objectives.

Table 3 – Example 1 Of Qualitative Consequence Assessment Criteria

Example 2 takes this approach a little further and provides two sets of criteria for assessing a risk . These are called in the JPL Process "Implementation" and "Mission" risk assessment criteria. A risk's severity can be assessed differently in Implementation and Mission Risk.

Adjective	Implementation Risk Criteria	Mission Risk Criteria
High	Not repairable within remaining resources allocated to the system provider	Level 1 Reqts. (Minimum Mission Success) not achieved
Significant	Depletes remaining reserves	Severely degrades minimum mission success OR significant degradation to nominal mission objectives
Low	Severe impact to remaining resources	Does not degrade mission success, but has measurable impact to nominal mission
Negligible	Measurable impact to resources	Has some impact on nominal mission objectives.

Table 4 – Example 2 Of Qualitative Consequence Assessment Criteria

Quantitative Criteria– These are cardinal criteria, at least in principle. They can be compared even within a grouping. They may be assessable over a range of values, or may be selectable from a discrete set of values (this latter approach again clouds the distinction with qualitative criteria, but this example is in this camp since the practitioners use the values to aggregate risks.) Examples of likelihood and cost-consequence-quantified criteria are shown below in tables 5 and 6. The approach is also used to assess mass, power impact, etc.

Adjective	Criteria
Very High	90%
High	50%
Medium	30%
Low	10%

Table 5 – Example Of Quantitative Likelihood Assessment Criteria

Cost Impact – Pick One
$5M
$2M
$1M
$500K
$200K
$100K
$50K
$20K
$10K

Table 6 – Example Of Quantitative Consequence Assessment Criteria

The features of this approach which advocates prefer is that they can develop a reasonable assessment of the overall risk to the resources of concern – by combining the likelihood and consequence. The generally used approach is to multiply them together to obtain (mathematically non-rigorously) a "risk cost" for each item. Those who are skeptical of this approach don't believe that the numbers can be sufficiently accurately assessed to make the values useful. The one or two successful examples of utilizing this approach found reasonable correlation between predicted and actual reserves usage, including that used for mitigation.

Decision-Making

Decisions are required to expend resources outside the planned budget items when risks can be proactively responded to; for example to mitigate risk, transfer risk from one project element to another, or any other approach suggested by the trade-off data studied. Trade-offs for risk decisions can be suggested by the mitigation options identified when the risk items are initially documented and assessed. The JPL RM process suggests that the identifier and/or the assessor identify a number of data elements associated with a risk item. These risk descriptors can be stored in an appropriate data-base, for use in making decisions, and tracking the results. Many projects use a simple EXCEL spreadsheet to record the risks, but others utilize a web-based system, especially if, as in many projects today, the participants are diverse and geographically separated.

Table 6 shows recommended data base fields describing an assessed risk.

- **Event Description**
- **Root Cause**
- **Owner**
- **Assessment**
    - **Implementation Risk**
        - **Likelihood, Consequences**
    - **Mission Risk**
        - **Likelihood, Consequences**
- **Mitigation Options**
    - **Descriptions, Costs, Risk Reduction**
- **Significant Milestones**
    - **Opening/ Closing of the Window of Occurrence**
    - **Risk Change Points, Decision Points for Mitigation Implementation Effectiveness**

Table 6 – Risk Data Items

Qualitative Analysis/Decisions – The severity of the risk is important in decision-making. Fig. 4 shows the widely used risk matrix.

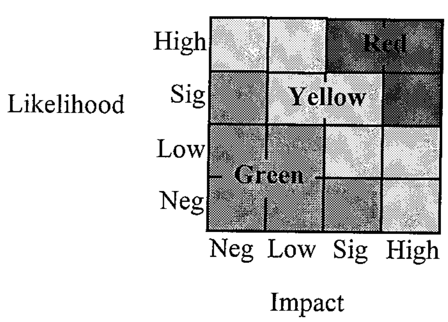


Figure 4 - Risk Matrix

The red, yellow, and green colors denote the project's categorization (prioritization) of severity. The project will often decide in the initial planning what the strategy is for handling risks in each severity category. This helps in defining and justifying reserve posture. Often the key decision is whether red risks are acceptable. This distinguishes risk-taking projects from those more averse to risk. Reporting and reviewing risk handling of red risks is more detailed than for yellow. Green risks are often just "watch" items.

Quantitative Analysis/Decision Making

The quantitative approach allows risk decisions to be evaluated on a cost-effectiveness basis. If the mitigation cost is significantly and credibly below the risk-cost, and within the reserve capability, the decisions to mitigate can be straightforward. The decision to exercise a number of mitigations (this may occur as the initial risk list is being compiled) may suggest a trade-off looking at different sets of mitigations, the costs and risk reductions achieved thereby, and the relative effectiveness of those options.

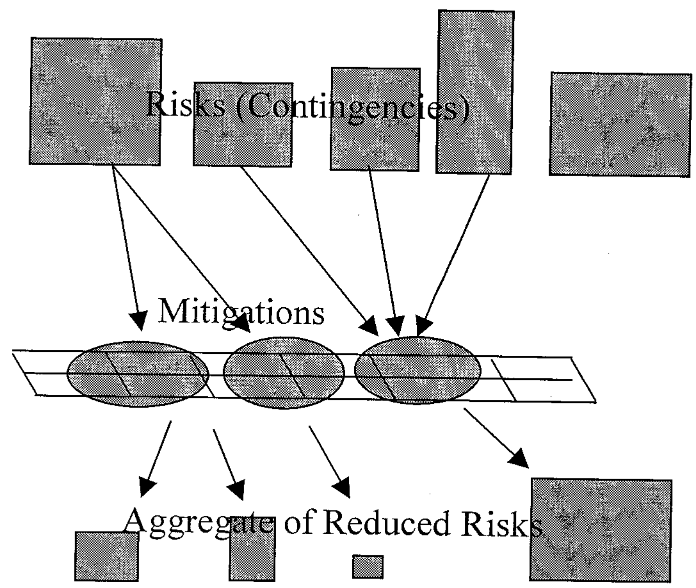


Figure 5 – Making Risk Mitigation Decisions

Fig 5 shows the concept of analyzing the effect of several mitigation options. The decisions made will affect the budgetary lien process, which ties Risk Management and Project Management integrally together.

The Lien Impact – The Risk impact on budget management is through the lien process. JPL Projects that do quantitative assessments include the Risk Costs as soft liens to the baseline budget, to track project exposure to risk. When mitigations are decided, the soft liens are reduced, and hard liens are added, with (hopefully) a net increase in available unconstrained reserves. When risks are realized, soft liens become hard liens. This process has been used successfully on the Stardust Project, which is now in operations.

Tracking

Risk Tracking involves the discipline of periodic updates to the risk data base. This is chiefly the responsibility of the

Risk Owner, and is accomplished in a variety of ways on JPL projects. The most effective way is a periodic "Risk Team" meeting with a regular frequency, and an established agenda and methodology. Other projects have had success with less formal ways, but this is also the area where the most frequent lapse of the RM process occurs. Risk team members have many competing priorities, and have not yet developed a culture at JPL where Risk Management is an automatic part of the engineer's attention. Triggers for risk reviews can be monthly management reporting requirements, quarterly customer review agenda items, a well-developed risk management milestone schedule, and the major reviews where it is expected that risks will be assessed.

An effective encouragement for risk tracking is the establishing of metrics pertinent to the identified risks. If the mass of the spacecraft is at risk, then frequent updates to the mass estimates, especially in the affected areas, is implemented. Since launch mass delivery capability is fixed, and therefore mass and power profile tracking at JPL is a major cultural element, this makes risk tracking of technical resources easier to accomplish in the project process.

The concept of Technical Performance Metrics (TPMs) is a recognized systems engineering process practiced at JPL for many years, and extensively used to track risk. The elements of TPMs are:

a) Planning the allocation of the resources and the reserve (margin)
b) Establishing the responsibility for maintaining current assessments of each TPM.
c) Using a standardized measuring format to ensure good communication.

Figure 6 depicts an illustration of the elements of a TPM tracking report. The various curves depict the triggers for closer attention. Our historical data shows that we are generally optimistic on the need for a resource. Thus allowance for growth is built in. Additional margin is assigned to known risk areas. And finally, the result must always be less than the allocated value (approved plan). Risk entails not only detecting growth larger than these assignments, but using the resource pro-actively to obtain the most performance possible. Thus the final result is expected to be near the approved level. Reallocation occurs as one negative margin (reserve) in one area is compensated through assigning excess margin from another.

5. Future Goals and Objectives

This paper has mentioned several aspects of Risk Management at JPL which is in process of being improved. They are summarized here, with a few ideas about what to do next.

Standardization Of Methodology

There are competing needs for this aspect of the process. As mentioned, Project Managers have a wide range of styles. Their ownership of the Risk Management activity is enhanced by installing methodology suited to their style. The use of qualitative or quantitative assessment is an example. On the other hand, reviewers, team members, management and customer would benefit by common criteria whereby the understanding of a "Red" risk (for example) would be consistent from project to project. This challenge is being attacked in two ways.

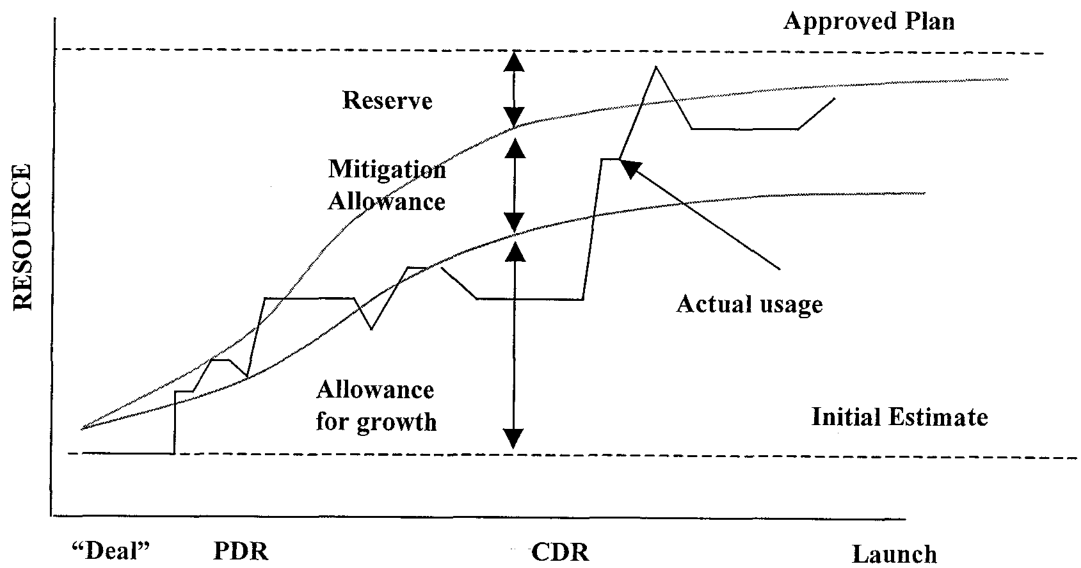


Figure 6. Technical Perfromance Measurement

One way is to establish the level of standardization at a deeper level. Where all agree now that assessing likelihood and consequence is needed, the next level of standardization would be the definitions of the measurables. By identifying the project resources as the measurables, including "Mission Success" measurables, we can provide better communication and better integration with the other management processes. It may not be necessary (or even practical) to try to standardize on the levels or degrees in the assessment, or on the specific resource values at each level.

The second way is training. JPL is revamping the training for Project personnel, and in the case of Risk Management, a spectrum of opportunities are provided to enable them to consider the advantages of the approaches we are proposing, and share valuable insight and experience with the Risk Management process engineers. In particular, a 2-day workshop is held at least quarterly, in which methodology is explained, and an interactive case study allows participants to develop the ideas into concrete data – which always results in benefits and insights for the student and the teacher. As a part of that workshop, current and recent past successful practitioners describe their lessons learned.

No Cultural Heritage for Doing RM

The common argument: "we have always done Risk Management on JPL projects", is often an honest statement of the care and insight seasoned Project Managers have applied to the desire to provide a successful mission. This indeed worked in a culture of a) few projects, b) experienced people ready to move onto the new project, and c) emphasis on safety, performance and assurance of success as the paramount concerns, with cost an important but modifiable resource, if needed. In today's environment, safety is first, cost second, and performance, while important, is the modifiable resource. In addition, there are 10 times as many projects, and many Project Managers are learning their trade on the job. This situation means that Risk Management must grow within the organization, and in the pool of current and potential project managers. This is happening, slowly, through the emphasis on Risk Management at the top level of management of JPL and NASA, and through the training program described above.

Credibility Of Quantitative Assessments

This concern is being attacked by encouraging the project management community to consider using quantitative methods where they can a) be believed, and b) be an effective use of the project resources. Experience from projects that have used them is a powerful testimony. Encouragement from the customer is a second. Refining of the techniques to makes the results credible, and conditioning expectations with realistic views of the outcomes are also needed from the analysts to encourage wider use. These practical evaluations of the analysts' results are occurring through looking at results from previous projects, and striving to develop and critique our analytic methodologies by iterating with project practitioners. This has been the hardest nut to crack, and there will be much more to report for the future.

6. SUMMARY

Risk Management has progressed at JPL in the 6-7 years it has been identified as a specific activity to be implemented on JPL flight projects. Every project currently in implementation has a Risk Management activity. Most projects are beginning Risk Management in the pre-project activity. The methodology identified in the JPL Risk Management process definitions is becoming more and more accepted and applied, with much tailoring to the needs and styles of the individual projects. Reviews and independent analyses are also using a common view of what risks are and how they are described. Pro-active use of resource reserves to mitigate identified risks is a specific result identified in reviews and status meetings.

There are things to improve. The Risk Management community – especially the aerospace element of it, which is most like the JPL experience – is contributing innovative and effective techniques that we embrace and incorporate, often encouraged by the projects. By far the most improvement is contributed by the using projects themselves. The methodologies practiced today are largely a result of the experiences of the previous projects. This is perhaps the best lesson. And the challenge to try the methodology and capture the experiences in order to reflect the successes "back to the future" is the challenge we are accepting.

ACKNOWLEDGMENT

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